Ka-Band GaN-on-SiC MMIC Balanced High Power Amplifier for NASA's Lunar Missions

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***Abstract*—The feasibility of Ka-band GaN-on-SiC MMIC based balanced power amplifier for science data downlinks from NASA's lunar mission assets in space is investigated. The balanced amplifier combines the RF output power from two power amplifiers using a rectangular waveguide based 3-dB hybrid coupler. The investigation includes characterizing the balanced amplifier for the overall RF output power, Gain, power added efficiency, RMS error vector magnitude for offset-QPSK, 8PSK, 16APSK, and 32APSK waveforms, 3rd order intermodulation products, and noise figure. The balanced amplifier has high output RF power and good linearity and can support high data rate downlinks from the surface and vicinity of the Moon to Earth.**

I. Introduction

NASA's Artemis program plans to build systems to support a sustainable human presence on the Moon and use the Moon as a steppingstone for a mission to Mars and beyond. The major components of the Artemis program are the Orion spacecraft, Space Launch System rocket, exploration ground systems, Lunar Gateway, Human Landing Systems, and the Artemis Base Camp or Habitat on the lunar surface [1]. Additionally, to support the Artemis program NASA has established a worldwide network of ground-based communications, navigation, timing, and tracking systems consisting of large diameter antennas. Furthermore, to ensure availability of adequate bandwidth to support the high data rate down links, the Agency plan is to use Ka-band as much as practical for telecommunication services.

Gallium nitride (GaN) has large bandgap, high electron saturation velocity, and good chemical stability. Silicon Carbide (SiC) has excellent thermal properties. Consequently, high electron mobility transistors (HEMTs) fabricated on epitaxially grown GaN on semi-insulation 4H-SiC wafers can operate at higher frequencies, deliver high RF output power with good linearity, and enhance the power added efficiency (PAE). Additionally, the HEMTs are radiation hard and can operate in the harsh environment of space [2]-[4]. Hence, GaN HEMT based monolithic microwave integrated circuit (MMIC) power amplifiers are suited for space flight systems. Furthermore, the theory and advantages of using a balanced amplifier configuration are explained in [5].

This paper builds on our previous development efforts on GaN MMIC based microwave power modules and single-ended power amplifiers [6]-[8]. In this paper, we extend the above effort to the demonstration of a Ka-band GaN MMIC based balanced high-power amplifier (HPA).

II. Ka-band Balanced High-Power Amplifier

A. GaN Balanced HPA Layout

The layout of the GaN balanced HPA is presented in Fig. 1. The balanced HPA employs waveguide (WR-28) based, 3-dB hybrid (90°) couplers at the input and the output to divide and combine the power, respectively. The center frequency (f_0) and bandwidth of the couplers are 27.5 GHz and $f_0 \pm 1.0$ GHz, respectively. The insertion loss and isolation of the couplers are 0.5 dB and 20.0 dB, respectively. The two GaN MMIC power amplifiers (PAs), whose output power is being combined, are HEMT based and internally matched to 50 ohms. Each PA delivers about 8 watts (CW) output power.

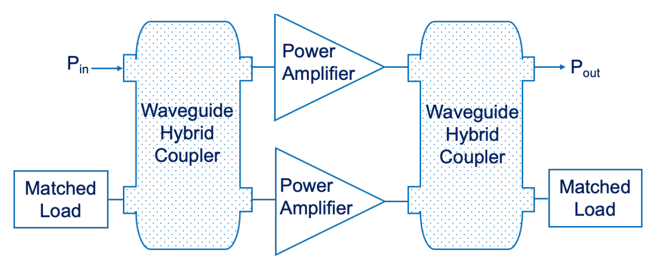

Fig. 1. GaN MMIC based Ka-band balanced high power amplifier layout. The power amplifiers are Qorvo TGA2595-CP.

B. GaN Balanced HPA Measured Characteristics

1) Output Power (P_{out}), Gain, and PAE: The measured output power and gain are presented in Fig. 2. The PAE is presented in Fig. 3.

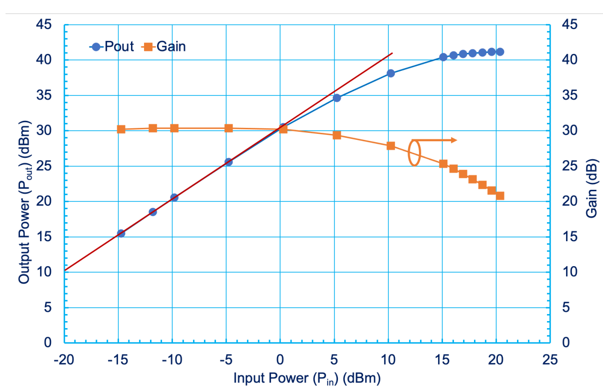

Fig. 2. Measured P_{out} and Gain vs. P_{in} of the balanced HPA at 27.5 GHz. $V_{d1} = V_{d2} = 20$ V, $V_{g1} = -2.2$ V and $V_{g2} = -2.15$ V, and T = 25°C.

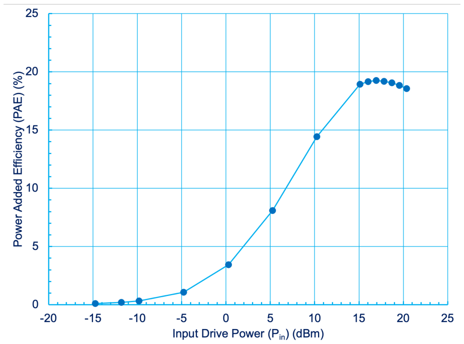

Fig. 3. Measured PAE vs. P_{in} of the balanced HPA at 27.5 GHz.

2) RMS Error Vector Magnitude (EVM): The measured RMS EVM at a fixed rate of 100 Msymbols per second for the Offset-QPSK, 8PSK, 16APSK, and 32APSK constellations are presented in Fig. 4. At the 1-dB compression point, the RMS EVM is less than 5% for the Offset-QPSK, 8PSK, and 16APSK constellations.

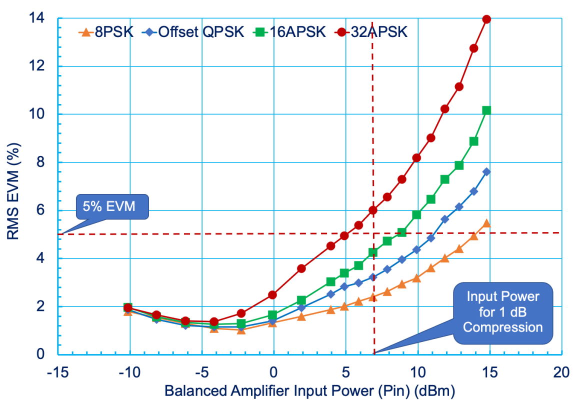

Fig. 4. Measured RMS EVM vs. P_{in} of the balanced HPA at 27.5 GHz. The symbol rate is 100 Msymbols per second and the square root raised cosine (SRRC) filter is set to 0.35.

3) 3rd Order Intermodulation Distortion (IMD): The 3rd order IMD are measured and the results are presented in Fig. 5. The OIP3 is 58 dBm.

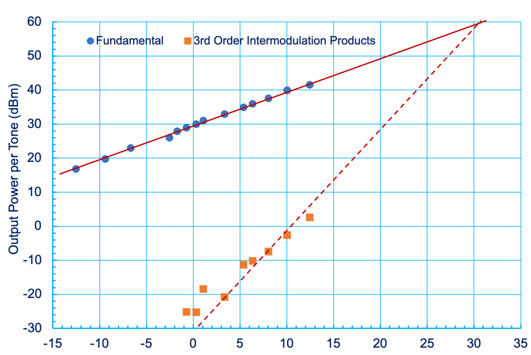

Fig. 5. Measured 3rd order IMD vs. input power per tone at 27.5 GHz. Tone spacing is 5 MHz.

4) Noise Figure (NF): The measured NF is presented in Fig. 6. The NF is less than 9 dB across the 27.5 to 28.5 GHz frequency range.

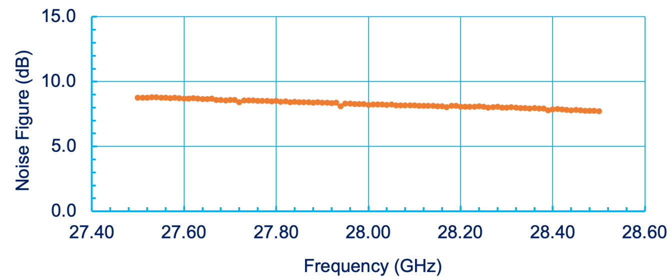

Fig. 6. Measured noise figure vs. frequency.

III. Conclusions and Discussions

The advantages of GaN for space applications is highlighted. The layout of the balanced high-power amplifier is presented. The measured P_{out}, Gain, PAE, RMS EVM for Offset-QPSK, 8PSK, 16APSK, and 32APSK constellations, 3rd order IMD products, and noise figure, are presented. The balanced amplifier has high output RF power and good linearity and can support high data rate downlinks from the surface and vicinity of the Moon to Earth.

Acknowledgment

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